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SIMULATION OF PERFORMANCE OF INTEGRATED GPS-NAVIGATION/FIRE CONTROL SYSTEM

by

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ABSTRACT Integrated GPS-navigation/fire control systems are described. On this foundation, descriptions are made of methods to simulate this type of system. In simulations, option is made for error and Kalman filter techniques. Simulation conditions are summarized in brief. In conjunction with this, results are given for two example cases.

KEY WORDS Geopositioning system, Geopositioning receiver, Kalman filter, Pseudo range and Pseudo range rate

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1 INTRODUCTION

As is widely known, due to digital computers and communications networks as well as the development of interconnection techniques, simulation technology for systems has brought with it progress in leaps and bounds. Simulation methods--from physical simulations--have advanced to digital simulations or mixtures of digital and physical simulations. Some are not able to reach the level of imitation. These simulations are capable of use in research on such things as principles and plans. They can also be used in such areas as preliminary engineering designs, system development, test measurements, integration, and so on.

Due to the development of computer and networking technology, it has led to an integration of satellite technology, communications network technology, aviation navigation and fire control technology. Combining satellite positioning technology and integrated avionics technology, one then forms global positioning integrated avionics systems. In the Gulf War, this type of system made the aircraft of multinational units unerringly attack key Iraqi targets, performing war exploits. On the basis of material introduced--before the development of this type of high technology integrated system--the U.S. had already done large amounts of simulation work.

Chinese satellite technology and communications technology both belong in the world's first rank, and digital or aviation navigation/fire control develop continuously. However, taking aviation and space navigation high technologies and fusing them, the brand new integrated systems formed still have a ways to go. During the course of this process, we require very serious attention to the research and development of simulation technology. Facts clearly verify that, in the development of an engineering project--from beginning to end--simulation development is a key, indispensable operation in all cases. If it is necessary to make engineering system design, development, test measurements, and integration stride forward in the correct directions, it is first of all necessary to get a good grasp on simulation research and construction.

2 A SIMPLE DESCRIPTION OF INTEGRATED GLOBAL POSITIONING-NAVIGATION/FIRE CONTROL SYSTEMS

As far as integrated global positioning-navigation/fire control systems are concerned, at the present time, there are two

types of basic modes. One type is as shown in Fig.1. This is a classical digital type modularized aviation electronics system. It has the constituent core modules below:

- central computer
- antenna coupling devices
- signal data converters
- inertial measurement assembly
- inertial measurement assembly buffers
- luolan (phonetic) receivers
- digital or graphic displays
- HUD displays.

Another type is global positioning digital type avionics systems. Their basic form is as shown in Fig.2.

The fundamental structure is a digital type network. Various individual subsystems are connected together by a 1553B main multichannel data line. Other areas will not need to be explained in any more detail.

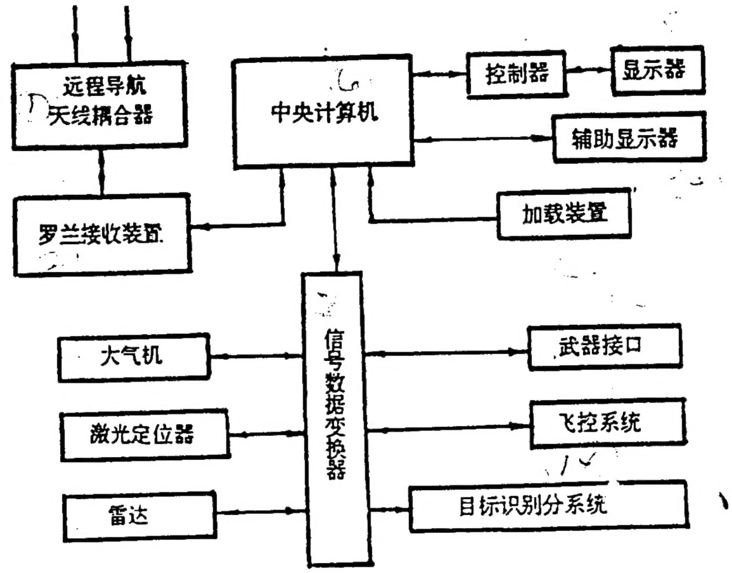

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Fig.1 Global Positioning Aviation Navigation/Fire Control System Line and Block Chart (1) Long Range Navigation Antenna Coupler (2) Luolan (Phonetic) Receiver System (3) Atmospheric Engine (4) Laser Positioning Device (5) Radar (6) Central Computer (7) Signal Data Converter (8) Control Device (9) Display (10) Auxilliary Display (11) Load System (12) Weapons Connection (13) Flight Control System (14) Target Recognition Subsystem

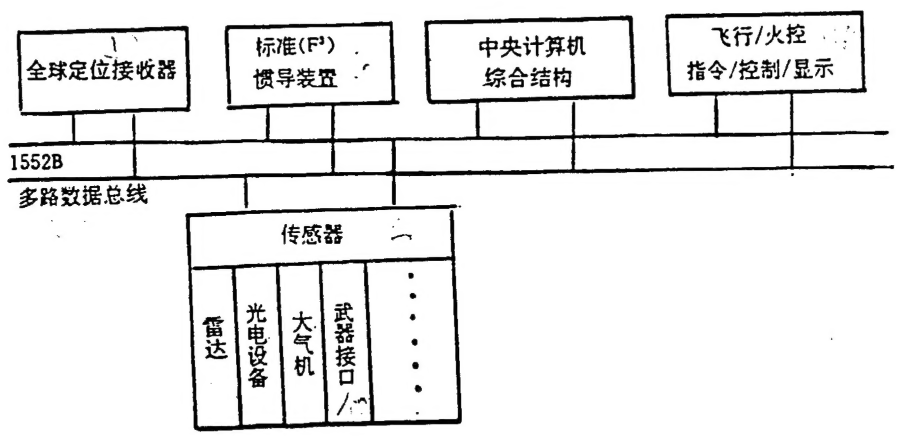

Fig.2 Integrated Global Positioning Avionics Structure (1) Global Positioning Receiver (2) Standard (F3) Inertial Guidance System (3) Central Computer Integrated Architecture (4) Flight/Fire Control Command/Control/Display (5) Main Multichannel Data Line (6) Sensors (7) Radar (8) Photooptical Equipment (9) Atmospheric Engine (10) Weapons Connection

3 SIMULATION DESCRIPTION

As far as the subject global positioning aviation navigation/fire control systems requiring research here are concerned, use is made of digital models of global positioning system receivers, inertial system model characteristics, navigation models, fire control aiming, and models or equations associated with weapons ballistics. Use is also made of dynamic characteristics of bombers and Kalman filter equations and arrangements. The simulation line and block chart is as shown in Fig.3.

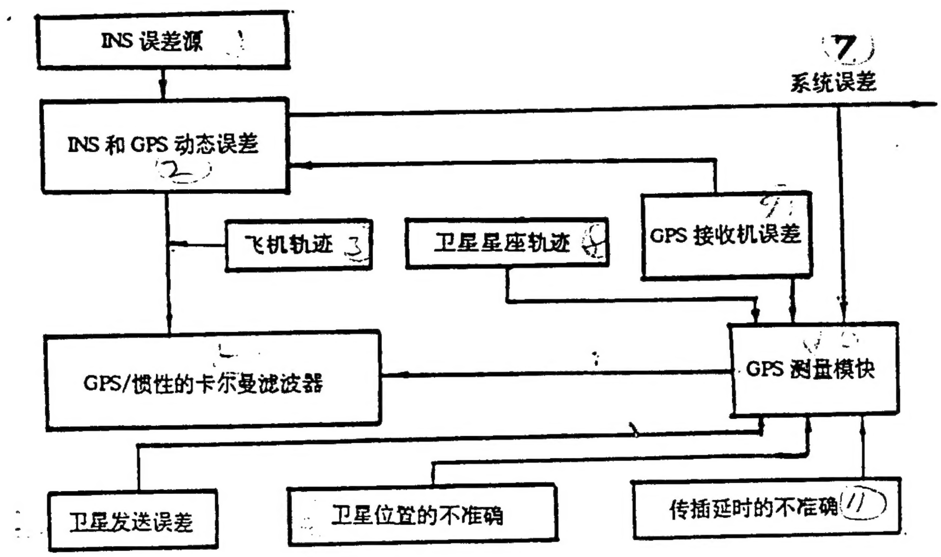

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Fig.3 Integrated Global Positioning Navigation/Fire Control System Simulation Line and Block Chart (1) INS Error Source (2) INS and GPS Dynamic Error (3) Aircraft Track (4) GPS/Inertial Kalman Filter (5) Satellite Transmission Error (6) Satellite Location Inaccuracy (7) System Error (8) Satllite Constellation Orbit (9) GPS Receiver Error (10) GPS Measurement Module (11) Transmission Inserted Time Delay Inaccuracies

Speaking in terms of navigational simulations, in principle, they are programed solutions of simulation equation sets, considering the influences of such sources of error as cross sections of given aircraft as well as INS/GPS and so on. Below are the principal steps associated with simulations:

a. Solving different equation sets. These equation sets include describing INS dynamic models as well as GPS sensors, and so on.

b. Using iterative substitution GPS and inertial Kalman filter algorithms, estimating effective INS and GPS errors, and, at the same time, carrying out integrations of various types of GPS and INS data.

Here it is necessary to stress the two key modules. One module is the INS and GPS dynamic error module. This module is obtained through the use of solutions for different equations. The other module is a GPS measurement module. Below, the basic characteristics of the two modules are introduced.

Dynamic error modules are obtained using solutions to different equations. The output of this module is integrations of various types of data related to global positioning systems and navigation positions--such as, speeds, deviation angles, platform verticality, and estimates of time period and clock drift errors. We opt for the use of different equations in order to study modules which show inertial errors and GPS errors. In these cases, second order angular deviation quantities are not considered. Certain second order angular deviation quantities can be put into INS calibration forms of simulations in order to simulate movements.

As far as GPS measurement modules are concerned, there are included among them four digital models to describe pseudo ranges and range rates. The output of this module is supplied by Kalman filters. There are distinctions in this type of output in the area of Kalman filter estimates associated with measurement functions and these measurements. These differences can be displayed using functions. Moreover, these functions and the various factors below are related.

a. GPS/inertial integration errors.

b. Such inaccuracies as satellite location, transmission time, signal propogation delay, and so on.

c. Errors given rise to by GPS receivers.

As far as aiming technologies studied in simulations are concerned, ballistic weapons treatments, and so on, are omitted.

Relevent errors in simulations and Kalman filter technology

will be elucidated below. /61

4 ERROR SOURCES

The contents of system error sources are many and various. Research on related fire control technologies, weapons, and sensors were introduced early on in a good number of references. We will do no more discussion in generalities, but focus the analysis on two error items. In simulations, option is made for different error equations: function equations associated with aircraft tracks and INS error sources as well as GPS error sources. INS error sources are set out in Table 1. GPS receiver error sources are as shown in Table 2.

5 Kalman Filter Treatment

In simulations, Kalman filter treatment is also an important link. Here, GPS/inertial Kalman filtering treatment includes handling four pseudo ranges and pseudo range rates, giving out estimates of these two. In conjunction with this, estimates are given of INS and GPS errors. In order to reduce GPS/inertial integration errors, in simulations of dynamic errors, it is possible--on the basis of the nature of the case--to consider putting them in, and it is also possible to take them out.

We simulate 11 types of conditions associated with Kalman filters. Among the variables listed below, 11 types of condition errors appear.

项 目	标准偏差	备 注
未校准	33sec	
刻度因子误差	0.05	
长项偏差	316μg	
短项偏差	20μg	
随机噪声	30μg	
加速度灵敏度比例因子	10^{-4} / g	
2 阶非线性	20μg / g^2	
重力偏移	25μg	修正距离 37 公里
未对准角误差	40Rec	
质量不均匀	0.17deg / hr / g	
非等弹性性	0.012deg / hr	
重复报告的偏移	0.012deg / hr	
随机误差	0.005deg / hr	
滚动测量误差		干扰噪声
俯仰测量误差		干扰噪声
方位测量误差		干扰噪声

Table 1 INS Error Sources (1) Item (2) Standard Deviation (3) Remarks (4) Uncalibrated (5) Calibration Factor Error (6) Long Deviation (7) Short Deviation (8) Random Noise (9) Acceleration Sensitivity Ratio Factor (10) 2d Order Nonlinear (11) Gravity Deviation (12) Unaligned Angular Deviation (13) Mass Nonhomgeneity (14) Anisoelasticity (15) Deviation Associated with Repeated Reports (16) Random Error (17) Roll Measurement Error (18) Pitch Measurement Error (19) Yaw Measurement Error (20) Correction Range 37 km (21) Interference Noise

	1 项目	2 精度
距离误差	空间飞行器时间误差	2.7m
	距离误差	1.5M
	天文历表模块滤波	3.1M
	天文历表予测误差	3.5M
	多路线误差	2.0M
	对流层延时误差	2.0M
	接收机通道延时变化	1.5M
	电离层修正不准确	2.3M
距离速率误差	距离速率误差	0.012M
	P码信号	0.02M～0.006M
	接收机振荡不稳定	0.03M / sec / Rec
	接收机振荡灵敏度	0.9M / Rec / g

Table 2 GPS System and Receiver Errors
(1) Item (2) Accuracy (3) Range Error (4) Range Rate Error (5) Space Flight Craft Time Error (6) Range Error (7) Ephemeris Module Error (8) Ephemeris Forecst Error (9) Multiple Path Error (10) Troposphere Delay Error (11) Receiver Channel Delay Error (12) Ionosphere Correction Inaccuracy (13) Range Rate Error (14) P Code Signal (15) Receiver Oscillation Instability (16) Receiver Oscillation Sensitivity

-- X speed

-- Y speed

-- Z speed

-- latitude

-- longitude

-- deviation angle (X acceleration figured relative to north)

-- X platform verticality

-- Y platform verticality

-- altitude

-- time

-- receiver clock drift error.

With regard to research related to Kalman filter equations, please refer to Reference [2]. A general solution and flow chart for these equations is described in brief in Fig.4. In this, the main parameters are:

$\hat{X}$ -- condition estimate

Φ -- condition transfer matrix

$\overline{W}$ -- time reset

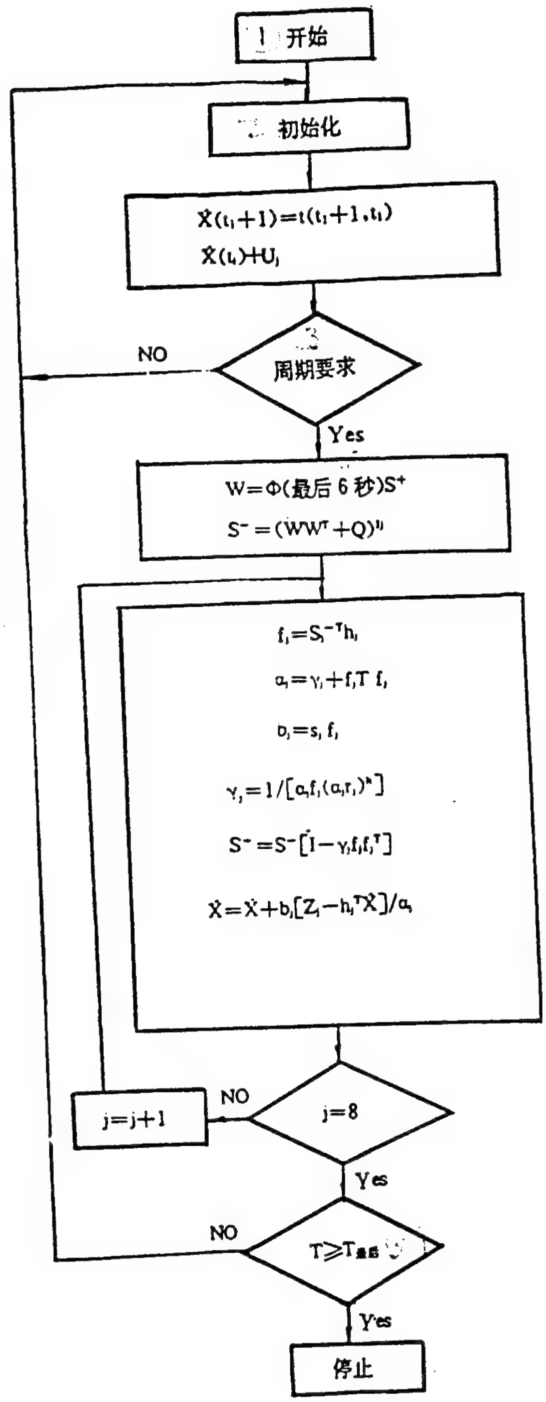

Fig.4 Kalman Filter Flow Chart (1) Start (2) Initialize (3) Periodic Requirement (4) Last 6 Seconds (5) Final (6) Stop

6 SYSTEM SIMULATION MOVEMENT CONDITIONS

Simulations of aircraft movement tracks exist in three dimensional coordiate systems. Aircraft move horizontally and vertically. Fig.5 is a schematic diagram descibing in simple terms aircraft flight cross section and ground track simulations for such things as GPS/inertial Kalman filter navigation.

In Fig.5, the upper line represents the aircraft flight track. The lower line, by contrast, represents the ground track. In flight, it is possible to set various types of interval time periods in order to record locations. In simulations, it is permited to make cross section corrections. Below, we take cross sections and add a brief explanation.

(1) Prescribed take off distance, aircraft speed, and linear, horizontal flight.

(2) Prescribed turning flight direction: 90°

(3) Prescribed climb and dive: minimum dive altitudes use 4g pull outs and return to 4600m altitude.

(4) After two severe turns, each section of linear flight is 2 minutes.

In simulations, GPS/inertial filters take several stipulated types of time periods to handle four pseudo ranges and range rates. Reception measurement noise added to ranges and range rates are handled in accordance with Gauss distributions. Integration intervals of range rate modules are set as 0.1 seconds. Noise sampling is once every 6 seconds. No consideration is given to interrelationships. That is simply to say that receiver noise uses dispersed white noise.

Errors in time period changes stipulate making one calculation each second. Within the interval of a second, independent terms are handled once each 0.1 seconds.

Recording speeds stipulated for aircraft cross section parameters are 10Hz.

7 SYSTEM SIMULATION RESULTS

During simulation movements, use is made in all cases of INS calibration forms and integrated GPS/inertial form performance. Here are listed three simulation movements:

(1) During simulation flights, INS calibration starting from the ground.

(2) As far as the second simulated dive attack is concerned, it starts from in flight INS calibration.

(3) With the conditions of movement #2, use is made of Kalman filters to handle GPS. /63

Fig.6 and Fig.7, which we present here, are nothing else than curves produced during simulation movements. In the Fig.'s there are several curves. The solid lines represent actual errors. These are produced during simulation movements. The two broken lines in the Fig. are 1σ error lines. Standard deviations (1σ) which act as one part of Kalman filter algorithms are relatively good. They are very close to the results using Monte Carlo statistics. Fig.6 shows latitude deviations. Fig.7, by contrast, shows longitude deviations. Besides that, there are also other results--for example, ranges, range rates, time periods, and other such simulation results. Due to limitations on the scope of this article, these are omited.

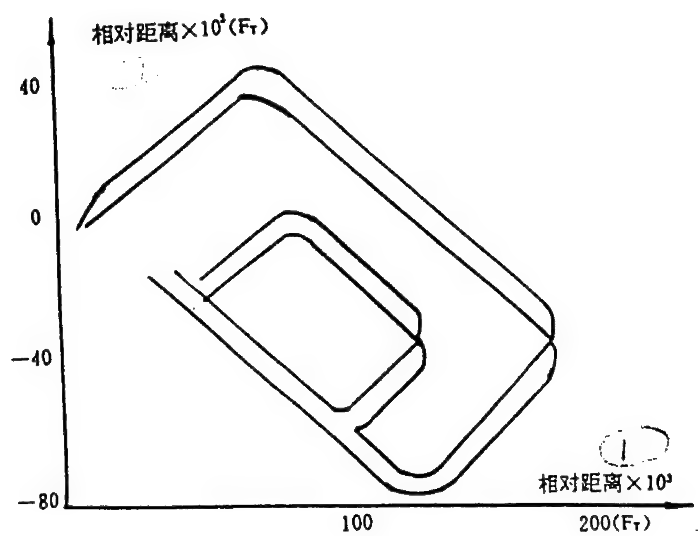

Fig.5 Simulation Flight Track Schematic (1) Relative Range

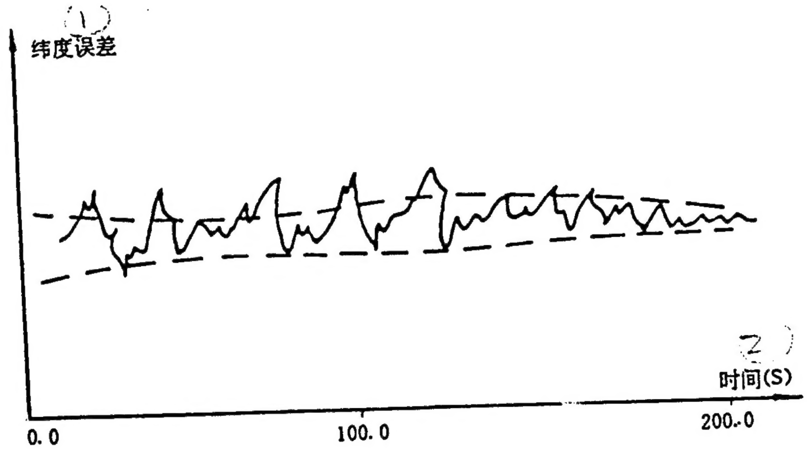

Fig.6 Simulation Latitude Error (1) Latitude (2) Time Period

From simulation movements, we obtained the conclusions briefly given below:

(1) Position errors change slowly. GPS range errors occupy the dominant position. Range errors are caused by satellite position inaccuracies and transmission time delays.

(2) Rate errors are transient. This is given rise to by inertial sensor measurement inaccuracies--for instance, ratio factor errors and receiver frequency sensitivities to aircraft accelerations. The influences on transients of "g" sensitivities associated with receiver oscillation are very great. Standard deviations associated with speeds in horizontal directions are 0.2m/s. Standard deviations associated with speeds in vertical directions are 0.3m/s.

(3) Spacial calibration convergence time periods are approximately 6 seconds.

(4) Clock drift transients and time errors are given rise to by oscillator frequency drifts when aircraft maneuver. Acceptable errors are 10 millimicroseconds. /64

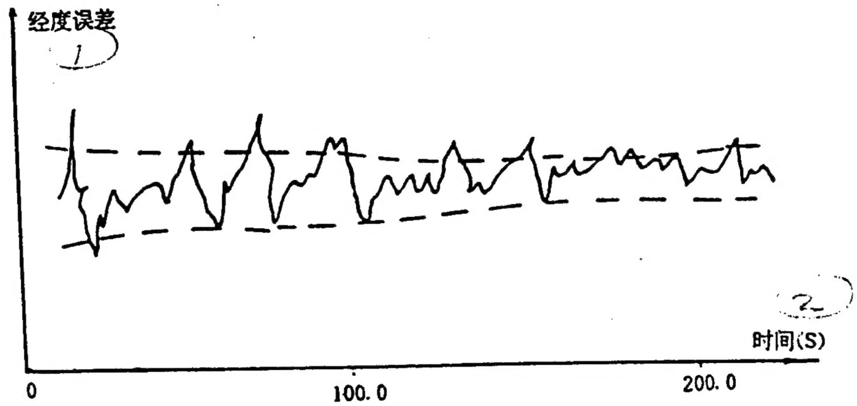

Fig.7 Simulation Longitude Errors (1) Longitude Errors (2) Time

As far as simulations of the release methods for weapons associated with fire control aiming are concerned, use is made of a series of bombs. Option is made for various types of dive angles and altitudes. Various types of aiming methods are used. Simulation results are set out in brief in Table 3. From the table, one can reach an important conclusion: fire control aiming systems opting for the use of GPS have quite high operational accuracies. The circumferential error probability (CEP) is generally 3-4 milli radians.

表 3 火控精度模拟结果

误差源	数值	脱靶误差		误差源	数值	脱靶误差	
		纵向	横向			纵向	横向
弹 道				校正误差			
• 散 布(mr)	3	10.50	7.39				
• 弹射速度(m/sec)	0.61	7.19	0.0	• 飞行员误差	–	–	–
• 释放退位(sec)	0.01	0.93	0.0	• 横向操纵(deg)	0.12	0.0	4.21
传感器				任务计划			
• 地面跟踪速度(m/sec)	0.20	1.80	1.80				
• 高度速率(/sec)	0.30	2.63	0.0	• 目标高度(m)	0.0	0.0	0.0
• 真速(m/sec)	1.53	0.50	0.0	• 目标位置(m)	0.0	0.0	0.0
• 飞机位置(m/sec)	9.01	9.01	9.01	• 弹道予计(m)	1.53	1.53	0.0
• 高 度(m)	13.73	14.10	0.0				
1σ 偏差		CEP=32.41m		CEP=3.93mr			

Table 3 Fire Control Accuracy Simulation Results (1) Error Source (2) Numerical Value (3) Target Miss Error (4) Longitudinal (5) Transverse (6) Error Source (7) Numerical Value (8) Target Miss Error (9) Longitudinal (10) Transverse (11) Trajectory (12) Scattering (13) Launching Velocity (14) Release Recovery (15) Calibration Error (16) Pilot Error (17) Transverse Control (18) Sensors (19) Ground Tracking Speed (20) Altitude Rate (21) True Speed (22) Aircraft Position (23) Altitude (24) Mission Plan (25) Target Altitude (26) Target Position (27) Trajectory Estimate (28) Deviation

REFERENCES

的，如被掩护目标所处的地形防御条件不同，防空兵用相同的作战效率，敌机使用普通炸弹临空轰炸和远距离制导武器攻击，目标的安全率也会有巨大差别的．所以用防空兵武器系统毁歼敌空中目标的概率和射击率，比较真实地反映出了防空兵的战斗效率指标．

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